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# A Multivariate Study of *Solidago* subsect. *Junceae* and a New Species in South America (Asteraceae: Astereae)

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**ABSTRACT.** A new South American species of *Solidago* L. (Asteraceae, Astereae) from Argentina, Chile, and Bolivia was identified within the subsection *Junceae* (Rydb.) G. L. Nesom. Using multivariate analyses on a matrix of 50 characteristics for 79 specimens, the distinctiveness of a South American *S. missouriensis*-like taxon was tested and determined to be statistically different from four morphologically similar North American species: *S. gattingeri* Chapm. ex A. Gray, *S. juncea* Aiton, *S. missouriensis* Nutt., and *S. pinetorum* Small. Therefore, a new South American species is proposed: *S. argentinensis* Lopez Laph. & Semple.

**Key words:** Argentina, Asteraceae, Astereae, biogeography, Bolivia, Chile, IUCN Red List, multivariate morphometrics, *Solidago*, South America.

In a recent taxonomic review of *Solidago* L. (Asteraceae, Astereae) in South America (Lopez Laphitz, 2009), two species of *Solidago* subsect. *Triplinerviae* (Torr. & A. Gray) G. L. Nesom were recognized: *S. chilensis* Meyen and *S. microglossa* DC. (Lopez Laphitz & Semple, 2011). In addition, the authors noticed that some specimens included among South American material were clearly morphologically very close to the North American *S. missouriensis* Nutt. Consequently, these specimens were excluded from the analysis of *Solidago* subsect. *Triplinerviae* and classified as members of *Solidago* subsect. *Junceae* (Rydb.) G. L. Nesom. Recent floristic treatments of *Solidago* subsect. *Junceae* have not included South American taxa. Only seven

species have been included in *Solidago* subsect. *Junceae*, and they all occur in North America and Mexico (Semple & Cook, 2006): *S. gattingeri* Chapm. ex A. Gray, *S. juncea* Aiton, and *S. pinetorum* Small from eastern North America; *S. missouriensis* from the prairies and Rocky Mountains from southern Canada to northern Mexico; and *S. confinis* A. Gray, *S. guiradonis* A. Gray, and *S. spectabilis* (D. C. Eaton) A. Gray from the mountains of the Great Basin, the Sierras and Coastal Ranges of California, and northern Baja California Norte. *Solidago* subsect. *Junceae* can be distinguished from other *Solidago* groups by having the basal leaves often present in rosettes at flowering, the proximal-most stem leaves petiolate to attenuate-subpetiolate, and the fascicles characteristically with small linear leaves on very short lateral branches in the axes of distal stem leaves (Semple & Cook, 2006). Strigulose stem pubescence is generally absent or confined to the inflorescence.

Although Brouillet et al. (2009) were successful in resolving the phylogeny of tribe Astereae using nuclear ribosomal ITS data, Schilling et al. (2008) reported a lack of resolution in the phylogeny of *Solidago* based on sequence data due to very low levels of variation in ITS and ETS sequences. Until phylogenetically informative sequences are discovered for *Solidago*, alternative nonmolecular methods must be utilized to assess species limits within the genus. This study used multivariate morphometric analysis to assess the distinctiveness of the South American *S. missouriensis*-like plants from related North American taxa within the subsection.



## MATERIALS AND METHODS

Herbarium specimens were examined from WAT, and additional specimens were borrowed from AA, CAS, DS, GH, JEPS, LP, MO, NCU, POM, RSA, TENN, and UC. Using previous analyses on the genus, descriptions of the taxa found in the literature (Semple & Cook, 2006), and personal observations, a list of the potentially useful traits was created (Appendix 1). In total, 50 morphological and floral traits were scored on specimens usually pressed during anthesis. Univariate and multivariate statistical analyses were performed using SYSTAT 10 for Windows (SPSS Inc., Chicago, Illinois, U.S.A.).

Discriminant analysis is a well-known tool in taxonomy and has been successfully used in *Solidago* (e.g., Heard & Semple, 1988; Semple et al., 1990; Cook et al., 2009; Lopez Laphitz & Semple, 2011); details of and justification for the methodology are not repeated here. Included in these analyses are tests for equality of group centroids (Wilks' lambda, Pillai's trace, and Hotelling-Lawley trace) and determination of Geisser assignment probabilities in placing each specimen a posteriori into each a priori group. Finally, a canonical discriminant analysis was used as a dimension-reduction technique to facilitate visualization of the results of the N-dimensional analyses.

A total of 627 specimens were examined, from which 220 were selected and measured for inclusion in the statistical analyses. All scored specimens were annotated with a label indicating that the specimen was included in the study. Preliminary analyses were performed including the seven taxa accepted for *Solidago* subsect. *Junceae*. Subsequently, a 79-sample matrix with the South American taxon and just the more morphologically similar central and eastern North American taxa was analyzed. The specimens assigned a priori to *S. juncea* had mainly three to 18 rays and had stems from short rhizomes or caudices. However, specimens that were identified as *S. missouriensis* had stems from elongated creeping rhizomes. Following Semple and Cook (2006), the number of rays and geographical distribution discriminated *S. pinetorum* and *S. gattingeri*. Specimens placed a priori in *S. pinetorum* came from the Piedmont and Atlantic Coastal Plain physiographic provinces in North Carolina, South Carolina, and southeastern Virginia, and had three to seven ray florets. Specimens of *S. gattingeri* came from Arkansas, Missouri, and Tennessee, and had five to eight ray florets. All of the South American individuals that had the traits of *Solidago* subsect. *Junceae* were placed a priori as *S. argentinensis* Lopez Laph. & Semple. An additional multivariate

analysis was carried out on a matrix created by combining the data on *S. argentinensis* with that for *S. chilensis* and *S. microglossa* from an analysis of South American subsection *Triplinerviae* by Lopez Laphitz and Semple (2011). This was done to confirm that no specimens of *S. chilensis* had been misclassified a priori as *S. argentinensis* because small specimens of the former species can sometimes look rather similar to specimens of the latter.

## RESULTS

The results of the preliminary analysis that included all the North American taxa indicated the three far-western species, *Solidago confinis*, *S. guiradonis*, and *S. spectabilis*, were in a group morphologically distinct from the eastern North American and South American taxa. Details are available from the authors. A discriminant analysis was subsequently performed on the 79-specimen matrix to determine which characters were most useful in separating the five species-level a priori groups: one South American (*S. argentinensis*) and four North American. The four characters with the highest F values selected in a stepwise discriminant analysis (midstem leaf lengths, leaf widths, inner phyllary lengths, and stem pubescence density; Appendix 1) were included in a complete discriminant analysis in decreasing order of discriminatory power. The F matrix based on Mahalanobis distances between group centroids, and associated probabilities indicate strong overall support for the five a priori groups (Table 1) and rejection of the null hypothesis that specimens of the five a priori groups were just samples of one group. All three tests for equality of group centroids (Wilks' lambda, Pillai's trace, and Hotelling-Lawley trace) indicated that the groups were significantly different (Table 2). The highest F values were between *S. argentinensis* and the North American taxa, and the lowest between *S. gattingeri* and *S. pinetorum*. Geisser a posteriori assignment probabilities were determined, and a classification matrix and a jackknifed classification matrix for the 79 specimens were generated (Tables 3 and 4, respectively). In the classificatory analysis, 14 of the 15 specimens assigned a priori to *S. argentinensis* were assigned a posteriori to that taxon. Twelve of these specimens, including the single Bolivian collection, had Geisser assignment probabilities between 97% and 100%, and two specimens, *Buchtiero s.n.* (GH) and *C. Castagnet 150* (LP), had assignment probabilities of 75% and 82% to *S. argentinensis*; the first of these was from Chile. Only one specimen, *T. M. Pedersen 14486* (MO), was



Table 1. F statistics,  $F_{0.05}$ , and associated null hypothesis  $P$  probabilities between the five putative taxa in *Solidago* subsect. *Junceae*;  $P < 0.0000$  in all cases.

a priori	a posteriori			
	<i>argentinensis</i>	<i>gattingeri</i>	<i>juncea</i>	<i>missouriensis</i>
<i>S. gattingeri</i>	34.367			
<i>S. juncea</i>	30.114	8.618		
<i>S. missouriensis</i>	33.881	8.733	4.545	
<i>S. pinetorum</i>	41.639	1.662	6.721	6.101

treated as misclassified a priori and placed a posteriori in *S. missouriensis* with an assignment probability of 60%; additional assignment probabilities for the specimen were 24% to *S. juncea*, 8% to *S. pinetorum*, and 7% to *S. gattingeri*. Of the 11 specimens assigned a priori to *S. gattingeri*, six were assigned a posteriori to that taxon with Geisser assignment probabilities of 75% and 86%, and one was assigned corrected to the species with only 45% probability. Three of the four misclassified specimens were placed a posteriori in *S. pinetorum* (50%–60% probabilities), and one was classified as *S. missouriensis* (53%).

Of the 14 specimens assigned a priori to *Solidago juncea*, 10 were assigned a posteriori to that taxon; four specimens had Geisser assignment probabilities between 71% and 100%, with six specimens between 49% and 67%. The remaining three specimens were misclassified, with Geisser assignment probabilities between 2% and 40%. Of 26 specimens assigned a priori to *S. missouriensis*, 15 were placed into that taxon a posteriori. Finally, of the 13 specimens assigned a priori to *S. pinetorum*, six were placed into that taxon a posteriori, with Geisser assignment probabilities between 49% and 56%. Three of these specimens were misclassified as *S. gattingeri* and *S. missouriensis*, with Geisser assignment probabilities of 78% and 52%, respectively.

Among the North American specimens classified a priori as *Solidago gattingeri*, *S. juncea*, *S. missouriensis*, or *S. pinetorum*, 10 specimens were assigned with ambiguous a posteriori classifications (one of *S. gattingeri*, two of *S. juncea*, four of *S. missouriensis*, and three of *S. pinetorum*). Geisser assignment probabilities for the 10 specimens were divided

among all four North American taxa, with no high assignment probability into a single a posteriori group.

A canonical analysis was performed and the variant scores were plotted on the first and second and on the first and third canonical axes for the five putative taxa studied (Fig. 1). The eigenvalues for the first canonical variate (3.139) accounted for 78.6% of the variation, the second (0.573) accounted for 14.4%, and the third (0.249) accounted for an additional 6.3%.

The results of analysis of *Solidago argentinensis*, *S. chilensis*, and *S. microglossa* confirmed that the three species were distinct. In the classificatory analysis, the 15 specimens treated a priori as *S. argentinensis* were all placed a posteriori in that species with 100% probability for all, including the single Chilean specimen, which resembled *S. chilensis* in general growth form.

#### DISCUSSION

Based on univariate analyses, discriminant analyses, and observations of herbarium specimens, a new South American species is recognized in *Solidago* subsect. *Junceae*: *S. argentinensis*. To assess the distinctiveness of *S. argentinensis* from North American members of *Solidago* subsect. *Junceae*, four species (*S. gattingeri*, *S. juncea*, *S. missouriensis*, and *S. pinetorum*) were compared based on their similarity to specimens of the South American taxon. Specimens of *S. argentinensis* formed a statistically distinct group clearly separate from the North American species-level a priori groups in the discriminant and canonical analyses. The percentages of specimens

Table 2. Multivariate statistics and F approximations for the Wilks' lambda, Pillai's trace, and Hotelling–Lawley trace tests for the discriminant analysis of the five putative taxa.

Statistic	Value	F values	df	P-tail
Wilk's lambda	0.119	13.476	16, 214	0.0000
Pillai's trace	1.351	9.351	16, 292	0.0000
Hotelling-Lawley trace	3.991	17.088	16, 274	0.0000



Table 3. Classification matrix obtained by classificatory discriminant analysis of the five putative taxa in *Solidago* subsect. *Junceae*. The number of specimens for each putative taxon are given in row categories and summed as columns.

a priori	a posteriori					% correct
	<i>argentinensis</i>	<i>gattingeri</i>	<i>juncea</i>	<i>missouriensis</i>	<i>pinetorum</i>	
<i>S. argentinensis</i>	14	0	0	1	0	93%
<i>S. gattingeri</i>	0	6	1	1	3	55%
<i>S. juncea</i>	0	1	9	2	2	64%
<i>S. missouriensis</i>	1	1	4	15	4	60%
<i>S. pinetorum</i>	0	2	1	3	7	54%
Totals	15	10	15	22	16	65%

correctly assigned a posteriori to *S. argentinensis* in the classificatory analysis and the Geisser assignment probabilities of individual specimens were generally higher than for placements and assignment probabilities for specimens of the four eastern North American species included in the study. The one specimen not placed a posteriori in *S. argentinensis* (Pedersen 14486, MO) was from Chubut Province, Argentina, in the southern portion of the species range, but was not overall morphologically distinct from other specimens of *S. argentinensis*. The combination of traits, however, made it aberrant for the species. It was placed a posteriori with 100% probability into *S. argentinensis* in the analysis comparing *S. argentinensis*, *S. chilensis*, and *S. microglossa*, the three native species of *Solidago* in South America. The results provide strong support for recognizing the South American plants as members of a separate, previously undescribed species in subsection *Junceae*. The results also indicate that the North American species can be very similar morphologically at times. The small number of specimens scored and the similarities in overall morphology among them are some of the factors that could be affecting the weak classification of these North American taxa. Further sampling is needed for these North American taxa before taxonomic conclusions about their status can be reached.

*Solidago* subsect. *Junceae* had not been reported in South America until recently by Lopez Laphitz (2009) and Lopez Laphitz and Semple (2011). This can be explained by the morphological similarities between *S. argentinensis* and another South American taxon, *S. chilensis*, which belongs to subsection *Triplinerviae*, such as the sparse indument on the inflorescence and upper stems, as well as by the lack of accurate or comprehensive taxonomic keys for the genus *Solidago* in South America (e.g., Sancho & Ariza Espinar, 2003). In addition, the overlapping distribution of *S. argentinensis* and *S. chilensis* in the Patagonian region and their probable sequential flowering season are also potential factors in the previous misidentification of the new species. Unlike North American members of subsection *Triplinerviae*, dwarf *S. chilensis* specimens can be as small as 15–20 cm tall, which would not be uncommon in *S. missouriensis* on the high plains in North America, but is at the very low end of the range in stem height of the *S. argentinensis* specimens examined. Thus, a usually reliable character such as stem height is sometimes misleading in South American species of *Solidago*.

While the introduction of *Solidago* into South America has not been studied in detail, the chance long-distance transport of the fruit propagules attached to the feathers of migrating birds is possible (Alan Graham, e-mail communication to J. C.

Table 4. Jackknifed classification matrix obtained by classificatory discriminant analysis of the five species-level a priori groups in *Solidago* subsect. *Junceae*.

a priori	a posteriori					% correct
	<i>argentinensis</i>	<i>gattingeri</i>	<i>juncea</i>	<i>missouriensis</i>	<i>pinetorum</i>	
<i>S. argentinensis</i>	14	0	0	1	0	93%
<i>S. gattingeri</i>	0	6	1	1	3	55%
<i>S. juncea</i>	0	1	8	3	2	57%
<i>S. missouriensis</i>	1	1	4	15	4	60%
<i>S. pinetorum</i>	0	3	1	3	6	46%
Totals	15	11	14	23	15	63%



Semple). The likely recent human-aided dispersal of *S. chilensis* back to multiple locations in the Northern Hemisphere (Lopez Laphitz, 2009 [West Indies]; Silva et al., 2009 [Madeira]) demonstrates that long-distance dispersal is not an obstacle in the genus. The relatively small sample of South American *S. argentinensis* collected between 1903 and 1986 provides little evidence for its point of origin. In general appearance, *S. argentinensis* resembles *S. missouriensis*; the two differ in stem pubescence, leaf size, and phyllary traits, but all other traits suggest a close relationship of the two species. A putative close relative of *S. chilensis* (*S. juliae* G. L. Nesom) and one of *S. argentinensis* (*S. missouriensis*) occurs in the same general area of northern Mexico today (Lopez Laphitz & Semple, 2011).

***Solidago argentinensis*** Lopez Laph. & Semple, sp. nov. TYPE: Argentina. Mendoza: San Rafael, Río Salado Superior entre Arroyos Vertientes Amarillas y Los Moros, 1940 m.s.n.m., 29 Jan. 1966, Ruiz Leal 24529 (holotype, LP). Figure 2.

Haec species *Solidagini missouriensi* Nutt. accedens, sed ab ea caulibus proximaliter sparsim distaliter dense strigulosis differt.

Herbaceous perennials from short to long rhizomes; stems erect, 18–50 cm tall, glabrate at the base, with increasing hair density distally, strigulose. Basal cauline leaves sometimes present at flowering and relatively large; midstem to distal cauline leaves much reduced distally, often subtending clusters (fascicles) of small lateral branch leaves; lower stem leaves petiolate, 20–80 mm including petiole, 3–14 mm wide, margin serrations 0 to 7; midstem leaves sessile, rapidly reduced upward, oblanceolate to lanceolate, 25–65 × 3–12 mm, margin serrations 0 to 5; upper and inflorescence stem leaves sessile, reduced lanceolate to linear, 12–58 × 0.5–5 mm. Inflorescences with heads paniculiform (pyramidal), nodding or secund, 5–21 × 2–6 cm; involucre 3.5–5.5 mm high; phyllaries in 3 or 4 series, the outer series ovate, the inner ones linear-ovate to oblong. Ray florets 6 to 19, strap 1–3 × 0.2–0.7 mm; disc florets 5 to 19, corollas 3–4.8 mm, lobes 0.6–1.5 mm. Cypsellae obconic, 0.5–1.2 mm; pappus bristles 3.2–5 mm. Chromosome number unknown.

*Distribution and habitat.* *Solidago argentinensis* is found from the Patagonian region of Argentina (Chubut, Neuquén, and Río Negro provinces) north to Mendoza Province. It has been collected from Juncal, Chile, and Valle de Cochabamba, Bolivia.

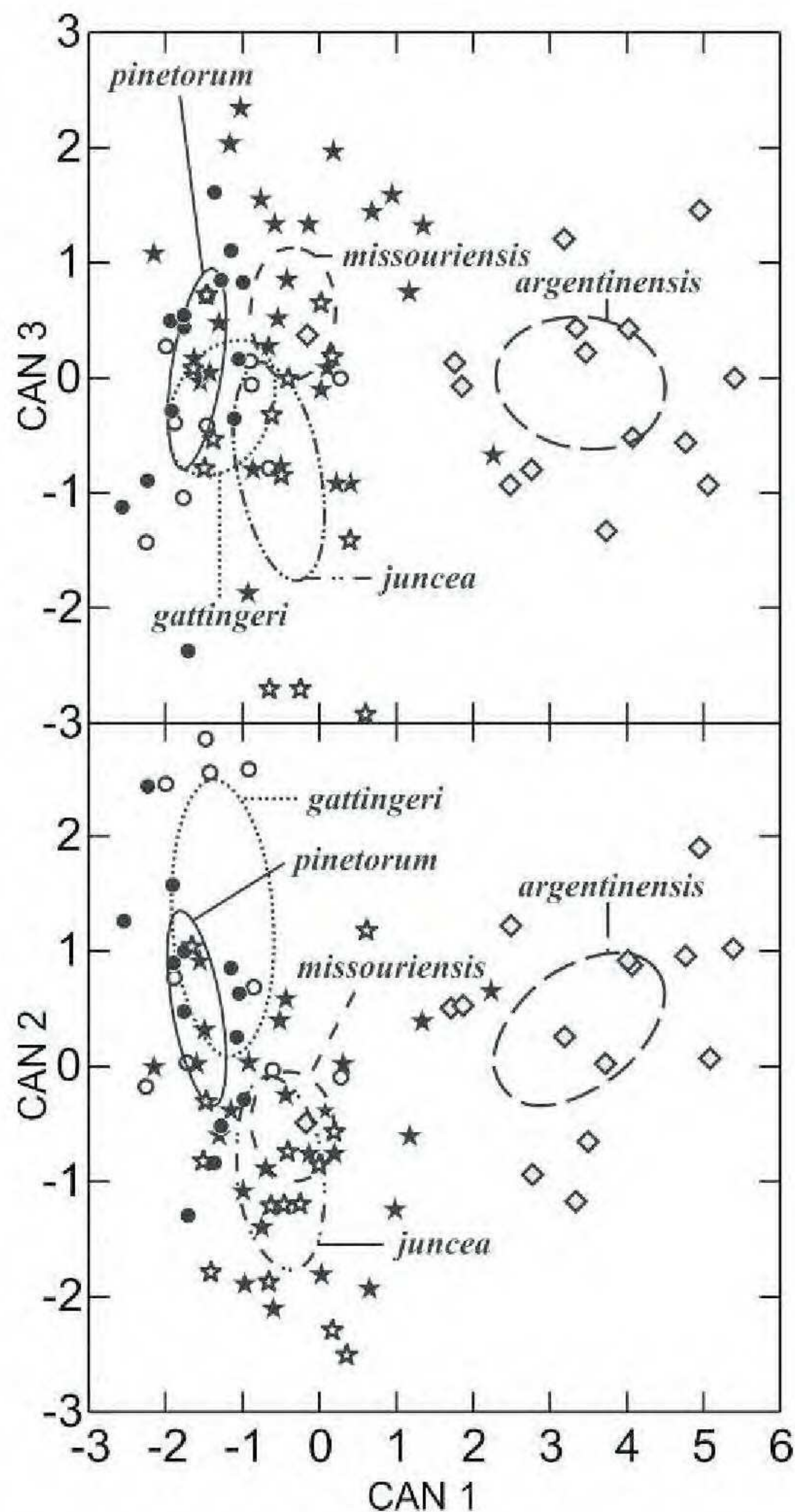


Figure 1. Plot of the first versus the second and the first versus the third canonical scores for 79 specimens of *Solidago* subsect. *Junceae* (matrix and analysis available from the authors). 95% confidence ellipses are indicated by broken and solid lines, with *S. argentinensis* represented by shaded diamonds, long-dash line ellipse; *S. gattingeri* by circles, dotted line ellipse; *S. juncea* by open stars, dot-dash line; *S. missouriensis* by solid stars, short-dash line ellipse; and *S. pinetorum* by dots, solid line ellipse.

*IUCN Red List category.* The new species is evaluated here as Data Deficient (DD) according to IUCN Red List criteria (IUCN, 2001).

*Phenology.* *Solidago argentinensis* has been collected in flower from January to early March.

*Paratypes.* ARGENTINA. **Chubut:** Nueva Lubecka, T. M. Pedersen 14486 (MO). **Neuquén:** entre La Rinconada y Junín de los Andes, A. L. Cabrera & J. Crisci 19130 (MO); Piedra Pintada, C. Castagnet 150 (LP); Trafal Norte, A. Soriano 84 (LP); entrada de camino al Huechulafquen desde Junín de los Andes, M. Lazago 3377 (LP); entre La



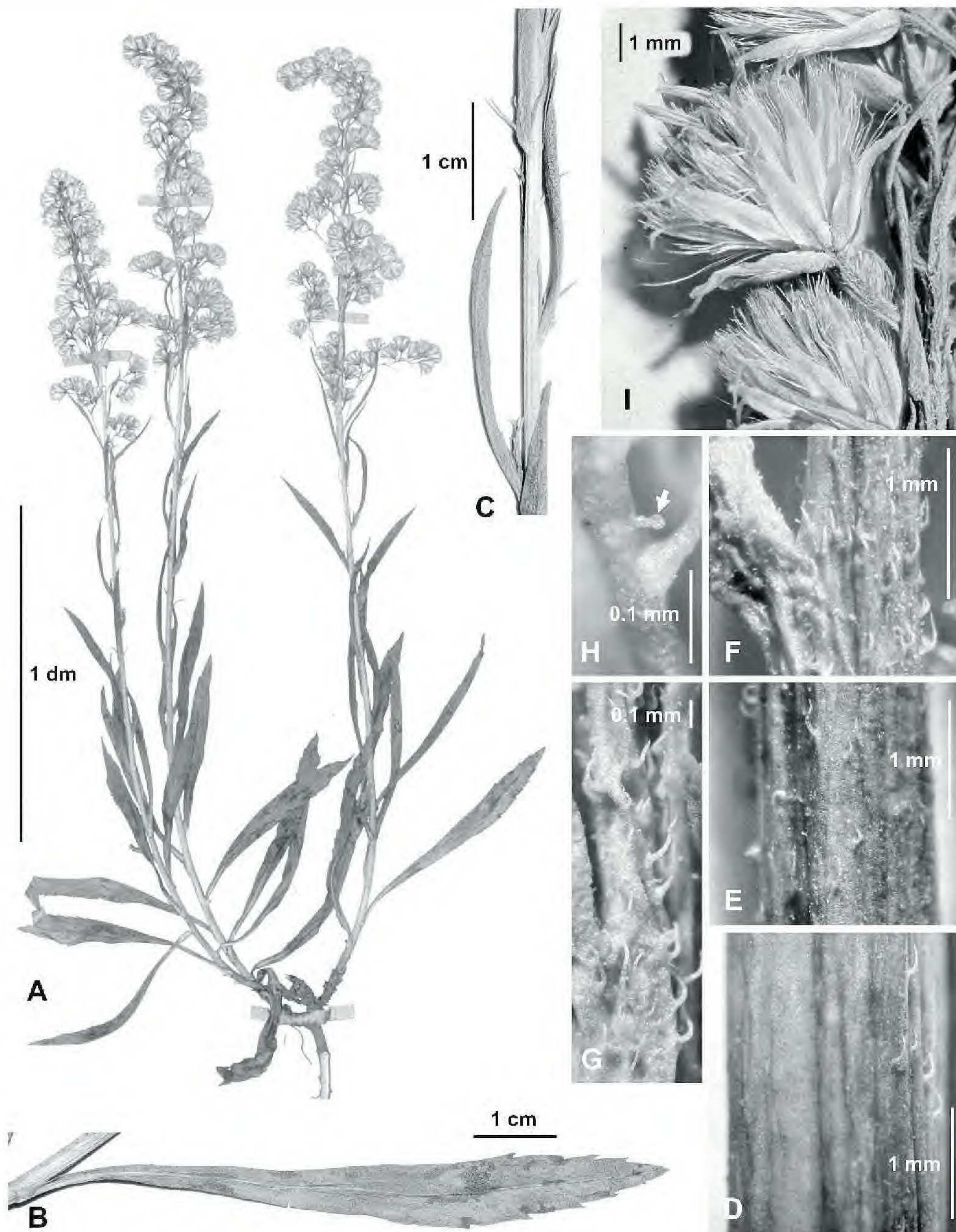


Figure 2. Holotype collection of *Solidago argentinensis* Lopez Laph. & Semple (Ruiz Leal 24529, LP). —A. Fertile shoots. —B. Lower stem leaf. —C. Middle to upper stem with lateral small lateral branch leaves. D–H. Stem and peduncle pubescence. —D. Lower stem, sparsely strigose. —E. Upper stem. —F. Mid inflorescence main stem. —G. Upper primary inflorescence axis. —H. Peduncle, base of hair and minute stipitate gland (arrow). —I. Inflorescence heads.

Rinconada y Junín de los Andes, A. L. Cabrera & J. Crisci 19130 (LP). **Río Negro:** Destacamento Militar (Parque Nacional Nahuel Huapi), R. De Barba 301 (AA); Puerto Pañuelo, region of Lago Nahuel Huapi, I. Rafael Cordini 121 (LP); camino al Tronador, C. Castagnet 74 (LP); San Carlos de Bariloche, A. Burkart 6586 (LP), A. Corte 291

(LP). BOLIVIA. Valle de Cochabamba, J. Steinbach 8795 (GH). CHILE. Juncal, 1903, O. Buchtiero s.n. (GH).

*Acknowledgments.* This research was supported by a Natural Sciences and Engineering Research Council of Canada Discovery Grant to J.C.S. and



University of Waterloo International Masters Student Awards to R.L.L. The National Park Administration of Argentina provided permits to collect in protected areas in that country. We gratefully acknowledge L. Becker for assistance in the field and G. Sancho (LP) for guidance with field trip preparations and completion. The curators of herbaria who loaned specimens are thanked for their assistance: AA, CAS, DS, GH, JEPS, LP, MO, NCU, POM, RSA, TENN, and UC. Joan Venn is thanked for her help with specimens at WAT.

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APPENDIX I. Morphological traits scored for *Solidago argentinensis* and related taxa from North America. Traits marked with an asterisk (\*) were not included in discriminant analyses because they correlated strongly (correlation coefficient of  $r > 0.7$ ) with another trait or the trait could not be

scored on many specimens. Traits marked with a pound symbol (#) were also excluded because they were used to identify a priori groups in some analyses.

- \*Stem height (cm); stem hairs: number of hairs counted on 1 mm on basal stem; \*stem hairs: number of hairs counted on 1 mm on midstem; \*stem hairs: number of hairs counted on 1 mm on upper stem; stem hairs: number of hairs counted on 1 mm on inflorescence stem.
- \*Hair length (mm) measured on basal stem; \*hair length (mm) measured at midstem; \*hair length (mm) measured on upper stem; \*hair length (mm) measured on inflorescence stem.
- \*Basal leaf length (cm) measured from leaf base to tip; \*basal leaf width (cm) measured at widest point; \*basal leaf measured from widest point to tip; \*basal leaf margins: number of serrations on one side of leaf margin.
- Midstem leaf length (cm) measured from leaf base to tip; midstem leaf width (cm) measured at widest point to tip; \*midstem leaf measured from widest point to tip (cm); \*midstem leaf margins: number of serrations on one side of leaf.
- Upper stem leaf length (cm) measured from leaf base to tip; upper stem leaf width (cm) measured at widest point; \*upper stem leaf measured from widest point to tip (cm); \*upper stem leaf margins: number of serrations on one side of leaf.
- Inflorescence leaf length (cm) measured from leaf base to tip; inflorescence leaf width (cm) measured at widest point; \*inflorescence leaf measured from the widest point to tip; \*inflorescence leaf margins: number of serrations on one side of leaf.
- Inflorescence length (cm) measured from base to tip; inflorescence width (cm) measured at widest point; length of the longest branch in the inflorescence (cm); \*distance between the first two branches in the base of the inflorescence; inflorescence angle formed between main stem and the branch measured from inflorescence.
- \*Height of involucre (cm).
- Outer phyllary length (mm) measured from phyllary base to tip; outer phyllary width (mm) measured at widest point; \*outer phyllary measured from widest point to tip (mm); outer phyllary vein number.
- Inner phyllary length (mm) measured from phyllary base to tip; inner phyllary width (mm) measured at widest point; \*inner phyllary measured from widest point to tip (mm); inner phyllary vein number.
- Ray florets: number per head; ray lamina length (mm) measured from corolla tube apex to lamina tip; \*ray lamina width (mm) measured at widest point; \*cypsela length (mm) at anthesis; ray floret pappus length (mm).
- Disc florets: number per head; disc corolla tube length (mm) measured from base to tip of corolla tube; disc floret cypsela length (mm) at anthesis; \*disc floret corolla limb length (mm); disc corolla lobe length (mm); cypsela: pappus length (mm).